# Study on Effect of 5 wt. % of Coconut Fiber Reinforcement on Tensile and Flexural Properties of Epoxy Based Composites

by

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Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Mechanical Engineering)

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# CERTIFICATION OF APPROVAL

Of Research Project

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(MECHANICAL ENGINEERING)

Approved by,

_____________________________

(AP. DR. OTHMAN MAMAT)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
MAY 2012

# CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.


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# ABSTRACT

Fiber reinforced polymer based composites have been used in many type of applications in industry for a long time for their high specific strength and modulus. In Malaysia, there are a lot of natural fibers available, thus in this study, an investigation has been carried out to make used of coir, the natural fiber as the reinforcement in reinforced polymer. Natural fibers are not only strong and lightweight but also they have relatively very cheap. The objective of the present study is to investigate the effect of 5 wt. % of reinforcement on tensile and flexural properties on coconut fiber reinforced epoxy composites and coconut powder reinforced epoxy composites. The study has shown that for 5wt. % of reinforcement, coconut powder reinforced epoxy composites have better tensile strength (31.67 GPa), Young's modulus (2.44 GPa), flexural strength (68.23 MPa) and flexural modulus (2518.85 MPa) compared to the coconut short fiber reinforced epoxy composites, with the percentage difference of 32.53%, 19.00 %, 41.89% and 15.34% respectively. Optical Microscope of fractured surface has been carried out to study their surface morphology and it shows that coconut powder reinforced epoxy composites have a better surface area and uniform distribution of coconut filler in the epoxy matrix.

# ACKNOWLEDGEMENT

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# TABLE OF CONTENTS

## LIST OF FIGURES

# LIST OF TABLES

# ABBREVIATIONS AND NOMECLATURES

| | |
|---|---|
| ASTM | American Society for Testing and Materials |
| COV | Coefficient of Variation |
| FRP | Fiber Reinforced Polymer |
| ISO | International Organization for Standardization |
| PE | Polyethylene |
| PEEK | Polyetherethrketone |
| PLA | Polylactic Acid |
| PMC | Polymer Matrix Composite |
| PP | Polypropylene |
| SEM | Scanning Electron Microscope |
| UTM | Universal Tensile Machine |
| UTP | Universiti Teknologi PETRONAS |

# CHAPTER 1
# INTRODUCTION

## 1.1 Background

Recently, there is a huge awareness of the importance for sustainable environment for development, which has increase the interested in using the natural fibers as reinforcements in petroleum-derived non-biodegradable polymers to replace the synthetic fibers. Natural fibers have many advantages, which are low cost, low density, unlimited sources and sustainable availability, low abrasive wear of processing machinery and more importantly, it is renewable resources [1]. Moreover, lately there are many studies and researches have been done on the bio-composites.

In this study, coconut natural short fibers (brown coir) and coconut powder have been used as reinforcement in polymer composites to produce a bio-composite material. This brown coir was thick, strong, high abrasion resistance as well as resistant to both salt and fresh water. These were one of the reasons why the coconut fibers were chosen as reinforcement.

Thermosetting plastic, also known as a thermoset was polymer material that irreversibly cures. One of the most commonly used thermoset in industry was epoxy resin, which it used as the matrix component in many fiber-reinforced plastics. Epoxy was also known as polyepoxide formed by the reaction of an epoxide resin with polyamide hardener. Generally, thermoset materials were stronger than thermoplastic materials due to this three-dimensional network of bonds (cross-linking) and also better suited to high temperature application up to decomposition temperature. However, they were more brittle and difficult to recycle. In this research, epoxy resin has been used as the matrix of the bio-composite material [2].

## 1.2 Problem Statement

Over a past few decade, the most conventional materials used as structural element in the industry are timber, concrete and steel. Materials that made of timber are easily to destroy by insect and fungi and also have a lower strength. Meanwhile, for the concrete has a high compressive strength but low in tensile strength. Even though, the steel structural elements have a good in resist tensile strength, but they were easily to corrode if they exposed to the environment condition for a long period of time. Recently, the production of structural elements made of fiber reinforced polymer (FRP) composites with synthetic fiber are widely used in industry, which they could provide high stiffness and strength to weight ratio and increased chemical inertness compared with the conventional materials. However, the FRP was highly cost material and not environmental friendly. Besides, the issue of wasting the abundant of natural fiber has caused the environmental problem. Therefore, in this study, the bio-composites were introduced to overcome the problem occurred.

## 1.3 Objectives of Study

The main objectives of the study were to investigate the effect of 5 wt.% of coconut fiber reinforcement on:

1. The tensile properties of Coconut Fiber Bio-composites.
2. The flexural properties of Coconut Fiber Bio-Composites under flexural load.

### 1.4 Scope of Study

In this study, there were two types of the reinforcement used, which were coconut coir short fiber and coconut powder with the weight percentage of 5 wt. % each. The matrix used was epoxy resin. The fabrication method was simple hand lay-up technique. There were two types of the conducted tests, which were tensile test and flexural test. Optical Microscope analysis has been done for the observation. The studied properties were tensile strength, Young's modulus, flexural strength and flexural modulus.

# CHAPTER 2
# LITERATURE REVIEW

## 2.1 Bio-composites

Bio-composites were composite materials made from natural fiber and petroleum-derived non-biodegradable polymers such as polypropylene (PP), polyethylene (PE) and epoxies or biopolymers such as polylactic acid (PLA). Bio-composite also can be derived from biopolymer and synthetic fiber such as glass and carbon, which were partially eco-friendly bio-composite. The eco-friendly or green composites were derived from natural fibers and crop or bio-derived plastic such as biopolymer [3]. Thus, in general bio-composite were composite materials compromising one or more phase(s) derived from biological origin and its composition was shown in Figure 1.

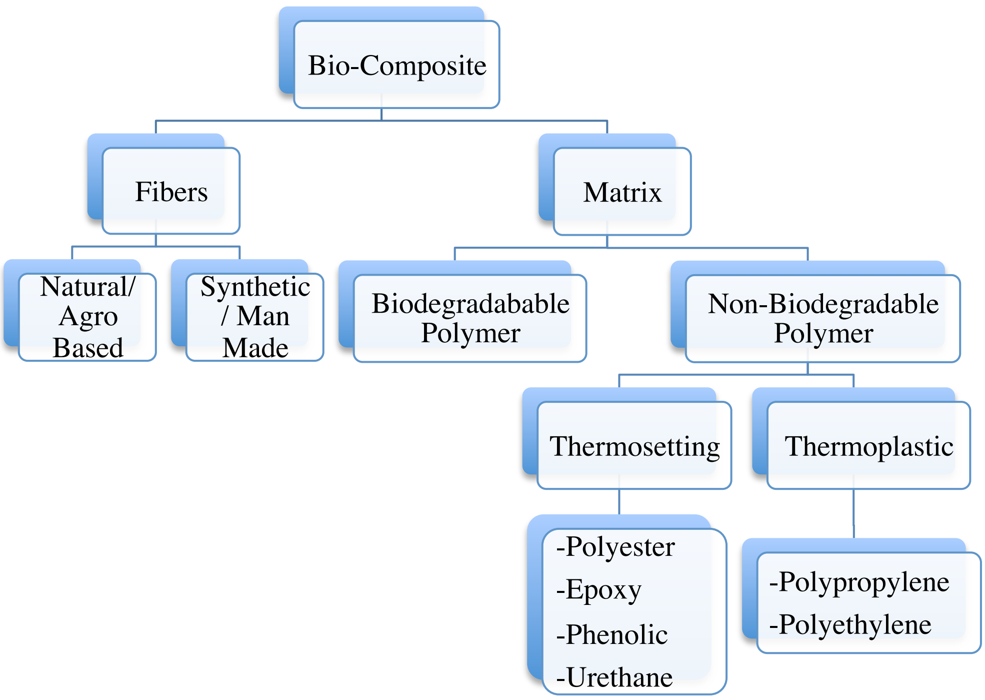



Figure 1: Composition of Bio-Composite [3].

Natural fiber sources were agro waste, which were abundant in agricultural sectors. The reinforcing bio-fibers comprise non-wood and wood fibers. The classification of reinforcing bio-fibers was shown in the Figure 2.

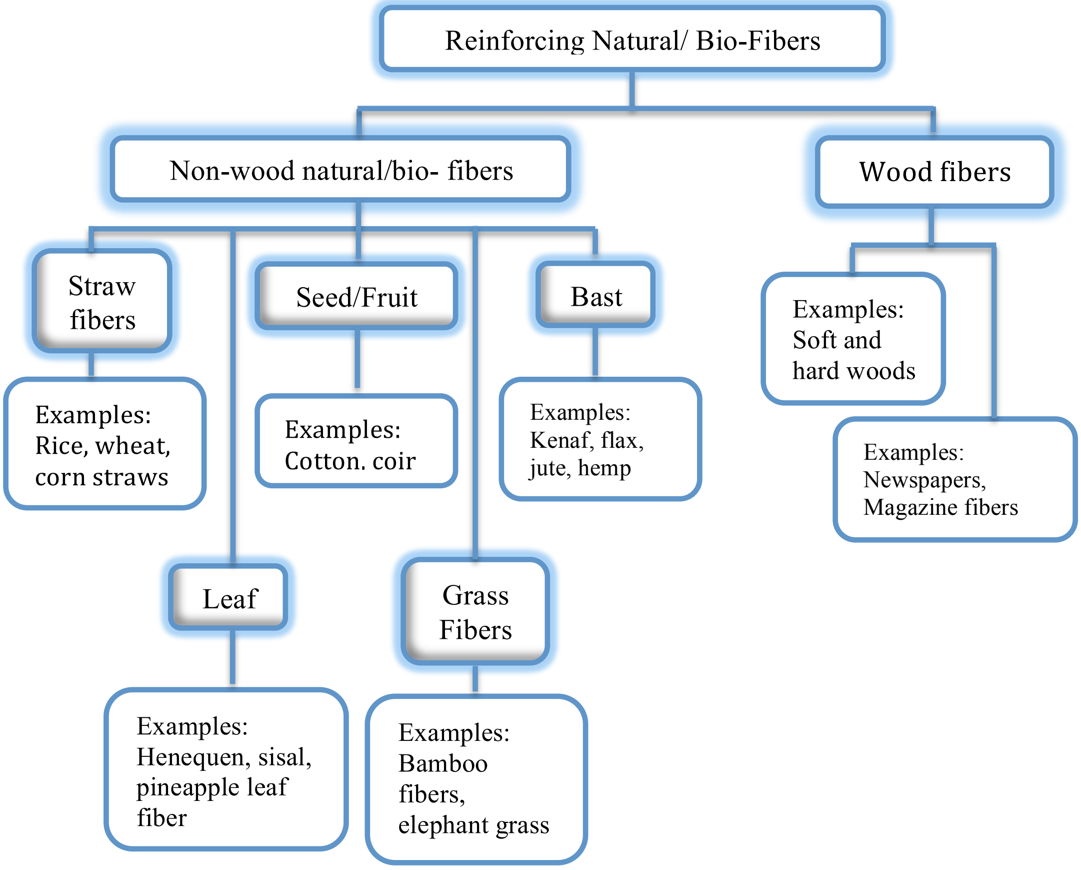



Figure 2: Schematic of reinforcing bio-fiber classification [4].

Fiber and matrix properties give a great influence on the mechanical properties of the composite. The tensile modulus was dependent on the fiber properties whereas the tensile strength was more sensitive to the matrix properties. Ahmad 2006, mentioned that strong interface, low concentration of stress and proper fiber orientation can improve the tensile strength of the bio-composite [5].

In this study the bio-composite was called Coconut Fiber Reinforced Epoxy Bio-composite. It was partially eco-friendly bio-composite. Therefore, the properties of the fibers, the aspect ration, and the fiber-matrix interface in the composite was important parameters that need to be considered in order to achieve consistency performance in the product properties of thermosetting composite.

### 2.1.1 Polymer Matrix Composite (PMC)

In structural application in the industry, the most commonly used as matrix materials was polymeric. The first reason of this was to overcome the inadequate of mechanical properties of polymers for many structural purposes by reinforcing other materials with polymers. Secondly, the manufacturing process of polymer matrix need not involved high pressure and does not required high temperature as well as the equipment used was simple. There were two types of polymer matrix composites, which were fiber-reinforced polymer composite and particle-reinforced polymer composite.

In fiber-reinforced polymer, fibers as the reinforcement were the main source of strength and carry the load along their longitudinal direction, while the matrix glues all the fibers together in shape and transfer stresses between the reinforcing fibers. The common fiber-reinforcing agents include carbon fibers, glass fibers, beryllium carbide, beryllium oxide, polyamide, natural fibers and others. Similarly, common matrix materials include epoxy, phenolic, polyester polyurethane, polyetherethrketone (PEEK), vinyl ester and others. Among these resin, PEEK was most widely used. Epoxy has higher adhesion and less shrinkage than PEEK, comes for its high cost.

In particle-reinforced polymer, particles such as small minerals particles, or amorphous materials were used to increase the modules of the matrix and to decrease the ductility of the composite. Besides, particles were used to reduce the cost and ease the process of manufacturing.

PMC materials have enhanced a wide interest in various engineering field, particularly in aerospace applications.

### 2.1.2 Characteristic of the Composites

Generally, composite material consists of two phases, which were one or more discontinuous phases embedded in a continuous phase. Discontinuous phase or called reinforcement was served to strengthen the composites and improved overall mechanical properties of the matrix and usually harder than the continuous phase or called as matrix. The matrix was usually more ductile, less hard, and holds the dispersed phase and shares a load with it.

The properties of the composites were strongly dependent on the nature of the constituent materials, the geometry and orientation of the reinforcement. The shape of the reinforcement, the size and size distribution, and volume fraction determine the interfacial area, which play an important role in determining the extent of the interaction between the reinforcement and the matrix.

## 2.2 Coconut Fiber

Coconut fiber was extracted from the husk of coconut. The chemical composition of coconut husk and coir fiber was shown in Table 1 [6]. Currently, it has been used with the reinforced of based thermosetting polymer composite in the application of furniture, building and even in automobile industries [7]. However, studies carried out so far have shown that coir fibers were not effective reinforcement for PMC [8]. The water absorbed into the lignocellulose surface of the hydrophilic coir fiber apparently prevents an efficient adhesion to the hydrophobic polymer matrix, which also happens in other natural fiber composite [9]. This consequence the incorporation of coir fiber tends to decrease the mechanical strength of the polyester composite for any volume fraction fiber. There were ways to increase this mechanical properties condition. One of the ways is through selection of thinner coir fiber. Thus, Monteiro and co-author [10], they fabricated with the thinnest fibers of sisal, ramie and curaua and it shows the improvement in the PMC mechanical properties. They concluded that the failure mechanism for higher strength composites reinforced with thinner fibers was a relatively more uniform rupture and greater more probability of having less structure defects [10].

Besides, coconut fibers were easily available. They also have been used for making a wide variety of floor furnishing materials, yarn, rope and others due to its hardwearing quality, durability and other advantages [11]. In addition, coconut coir was the most interesting product as it has the lowest thermal conductivity and bulk density as compared to other natural fibers [12]. Thus addition of coconut coir yields to a lightweight product of composite materials, which would solve environment and energy concern [13]. In other research, coir fiber-polyester composite with coir loading ranging from 9 to 15-wt%, have a flexural strength of about 38MPa [14].

Although a lot work has been done on coir fiber reinforced polymer composites, very rare and limited work has been done on the effect of reinforcement size and shape on mechanical behavior of composites. Against this background, in this study has been undertaken with the objective to study the effect of reinforcement size and shape on the tensile strength of polymer-based composite.

Table 1: The chemical composition of coconut husk and coir fiber [6].

| Properties | Percentage |
|---|---|
| Total water solubles | 26.00 |
| Pectins (soluble in boiling water) | 14.25 |
| Hemi-celluloses | 8.50 |
| Lignin | 29.23 |
| Cellulose | 23.81 |

**2.3 Resin**

Resin is a hydrocarbon secretion of many plants, particularly coniferous trees. A long time ago, resin was used to varnish materials for decorative and protective purposes. Recently, there are a lot of functions of the resin were discovered, from adhesive to varnish and others. There were several derivations made by using the natural resins; being the most used the synthetic resins from thermoset and thermoplastic groups. Table 2 presents the polymer behavior with origin groups from thermoset [15].

Table 2: Properties of typical thermoset polymers for natural fiber composites [15].

| Properties | Polyester | Vinylester | Epoxy |
|---|---|---|---|
| Density | 1.2-1.5 | 1.2-1.4 | 1.1-1.4 |
| Elastic Modulus (GPa) | 2-4.5 | 3.1-3.8 | 3-6 |
| Tensile Strength (MPa) | 40-90 | 69-83 | 35-100 |
| Compressive Strength (MPa) | 90-250 | 100 | 100-200 |
| Elongation (%) | 2 | 4-7 | 1-6 |
| Cure shrinkage (%) | 4-8 | - | 1-2 |
| Water absorption (24h @ $20^0$C) | 0.1-0.3 | 0. 1 | 0.1-0.4 |
| Izod Impact, Notched (J/cm) | 0.15-3.2 | 2.5 | 0.3 |

A green resin was called as bio-resin was one of the alternatives as the depletion of the petroleum and the constants concern for the environment. This bio resin offers an interesting potential for the use of various application compared with the natural resins, which are cannot be used for the purpose of the project.

Bio-resin was a resin system based on vegetal oil and/or other natural ingredients. The main advantage of the bio-resins was they were suitable for all major fibers and were compatible with polyester and epoxy substrate, present the major characteristics the free odor and shrinkage, the free toxic fumes without being flammable. They also can be found in the industry application for alternative energy, in construction and transportation. These bio-resins can be processed with the methods of simple hand stirring technique, autoclave, resin transfer molding and spray systems depend on its viscosity and thixotropic characteristics. The general characteristics of the bio-resins are shown in the Table 3 [15].

Table 3: General characteristics of Bio-resins [15].

| Characteristics | Bio-resin Basic Formulation |
|---|---|
| Gel time $25^0$C | 30-40 minutes |
| Mixture viscosity $25^0$C | 750 cps |
| Mix ratio by volume (resin/polymer) | 1:0.5 |
| Density (g/cm) $20^0$C | 1.1 |
| Water absorption (%) | <1 |
| Shelf life (month) | 12 |

### 2.4 Tensile Test

ASTM and ISO are the standards that usually been applied for the composite mechanical testing. ASTM D3039 was the standard being applied for reinforced composites for tensile testing [16]. Bernasconi et al, they have utilized ISO527-1 as the standard for testing to characterize the mechanical properties of glass fiber by using an MTS Alliance RF150 machine with the crosshead speed of 5 mm/min [17]. They also measured the strains by using the MTS 634.25 extensometer of 50 mm base length. However, in other research paper, Biswas et al, they applied the ASTM D3039 for tensile properties of fiber resin composites with the length of the test section of 200 mm [18]. The tensile test was performed in the universal testing machine (UTM) Instron 1195 and the result of the test is shown in Table 4.

### 2.5 Flexural Test

Flexural test is the most frequently employed to examine the behavior of the composite material. A rod specimen was having either a circular or rectangular cross section was bent until fracture using a three- or four-point loading technique. The three-point loading scheme was illustrated in Figure 3 [19].

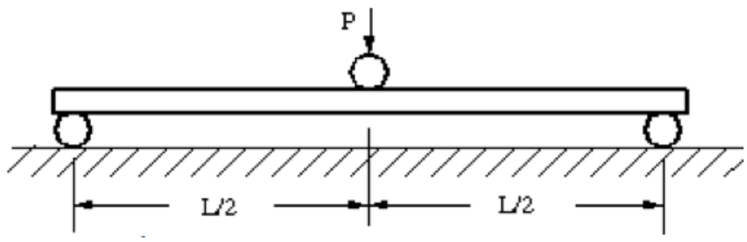



Figure 3: A three-point loading scheme for flexural test [19].

In Biswas et al. research, they conducted the flexural test as per ASTM D2344 using the same UTM Instron 1195 with the span length of 40 mm and the cross head speed of 10mm/min were maintained [18]. The flexural test result of fiber resin composites was shown in Table 4. They used the Equation 1 as shown to determine the flexural strength of the composite specimen.

Flexural Strength, $\sigma_{fs} = \frac{3PL}{2bt^2}$.....Equation 1

Where, $P$ is maximum load, $L$ is the span length of the sample, $b$ is the with of the specimen and $t$ is the thickness of the specimen.

Table 4: Tensile strength, tensile modulus and flexural strength for coconut fiber resin composite [18].

| Composite | Tensile strength (MPa) | Tensile Modulus (MPa) | Flexural Strength (MPa) |
|---|---|---|---|
| Epoxy (70wt.%) +Coir Fiber length 5mm (30 wt.%) | 3.208 | 1.331 | 25.41 |
| Epoxy (70wt.%) +Coir Fiber length 20mm (30 wt.%) | 9.155 | 1.518 | 31.28 |
| Epoxy (70wt.%) +Coir Fiber length 30mm (30 wt.%) | 13.050 | 2.064 | 35.42 |

**2.6 Observation**

Both optical and Scanning Electron Microscope (SEM) was required for the observation to analyze the composite microstructure condition. Through these observations, any defects mechanics can be analyzed. According to the Biswas et al. research, the surface of the specimens was examined directly by SEM JEOL JSM-6480LV. The fracture surface study of coconut coir reinforced epoxy composite after the tensile testing and fracture testing have been shown in Figure 4 [18].

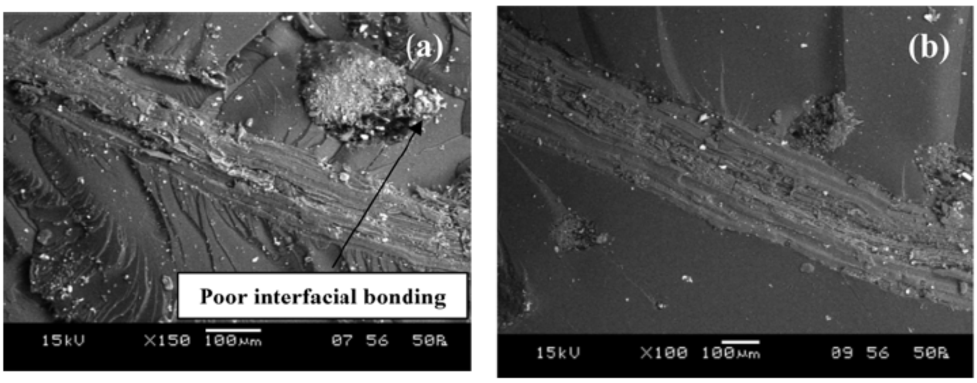



Figure 4: Scanning electron micrograph of coir/epoxy specimens after a) Tensile testing and b) Flexural testing [18].

# CHAPTER 3
# METHODOLOGY

## 3.1 Project Flow Chart

Basically, three main tasks were carried out through out this study in order to achieve the objectives of study. The first task was the preparation of the bio-composite material by combining the epoxy resin and coconut fiber after as received coconut fiber was grinded via grinding machine. Then, it was continue by performing the tensile test and flexural test to determine the tensile strength, tensile modulus and fracture strength of the studied bio-composite. Lastly, the microstructure analysis was carried out via the optical microscope. Figure 5 shows the whole processes of study.

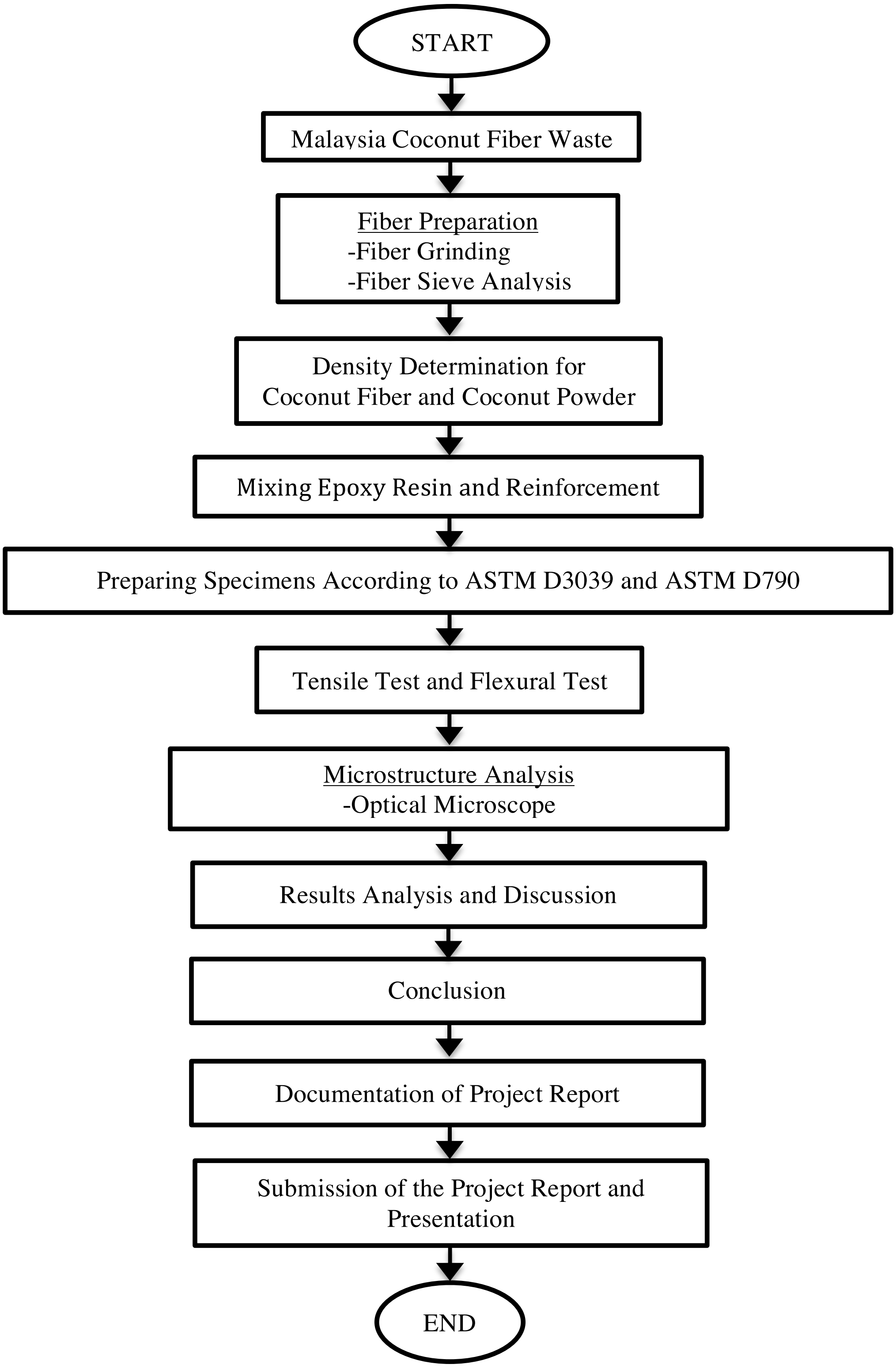



Figure 5: Activities flow chart of the whole research project.

### 3.2 Material

The studied composites materials were made of the coconut short fibers reinforced with epoxy resin matrix, which the fibers were arranged in discontinuous randomly oriented configuration and coconut powder reinforced with epoxy resin. The reason was to study the effect of reinforcement size and shape on the tensile and flexural strength. Basically, the raw coconut coir fibers were collected from Johor, Malaysia and they were obtained from the coconut husk, which was abstracted from the coconut fruit. Then, as received fibers were inserted into the Low Speed Granulator SG 16-21 machine to cut into smaller pieces. The maximum length of the fibers was round 2.0 cm after grinded. Then, the grinded fibers were categorized into different diameter range by using the sieve machine to analyze the distribution of diameter of the fiber. During the sieve process, the too long fiber and the contaminants such as small leaves will be separated out. A specific range of diameter fiber was selected to fabricate the bio-composite in order to have more consistent result. Thus, the coconut short fiber and coconut fiber were used in the study.

The usage of the epoxy resin as a matrix was chosen because of it was the standard economic resin commonly used as well as it was preferred material in the industry. The epoxy resin was prepared by mixing epoxy resin with hardener at weight ratio 10:6.

### 3.3 Density Measurement for Reinforcement

The density determinations for coconut fiber and coconut powder were obtained by using the Archimedes' Principle [20]. This principle states that every solid body immersed in a fluid apparently loses weight by an amount equal to that of the fluid it displaces. The equipment used for this experiment called METTLER TOLEDO balances. At first, the coconut fiber and coconut powder must be in a compacted form with the diameter of 23.00 mm and thickness of 4.00 mm by using the Autopallet Press Machine under the powder metallurgy process. The reason was to have small and compacted specimens that can be placed on the balances. The pressures used for compaction process for both types of reinforcement were 500 kg, 600 kg and 700 kg.

The die used for powder metallurgy process was 65 mm x 65 mm, x 65 mm with a 23 mm hole in the center. The punch was tool steel and fabricated as a rod with a 23 mm in diameter and 73 mm long. About 1 gram of the reinforcement was placed into the die. Figure 6 shows the die and punch set up in the Autopallet Press Machine.

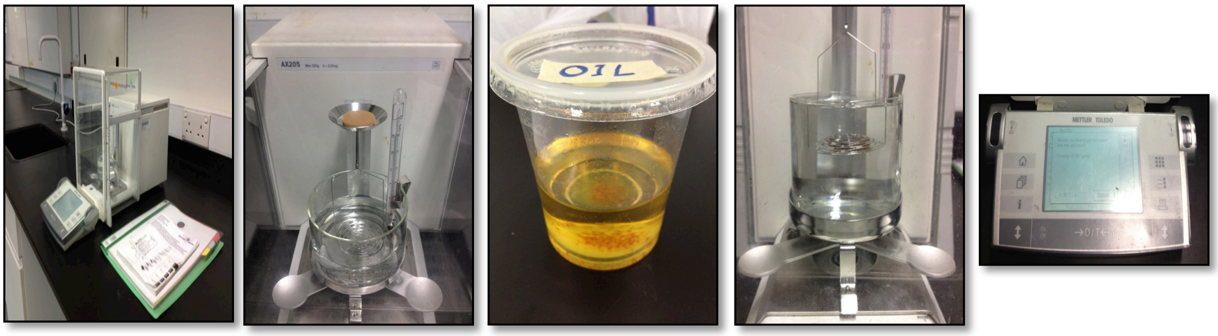

Figure 6: Punch and die set up in the Autopallet Press Machine used under the compression loading condition.

After all the compacted specimens have been prepared for both coconut fiber and coconut powder, the second step was to measure the density of the compacted specimens by using the balances. This device can calculate and give the density value automatically when the specimens were put into the balances according to the setting that has been set up. However, Equation 2 also has been used to calculate the density of the specimens to compare the result between theoretically and experimentally [20].

$$Density: \rho = \frac{A}{A-B}(\rho_0 - \rho_L) + \rho_L \text{.........Equation 2}$$

Where: ρ is density of sample, A is weight of sample in air, B is weight of sample in the auxiliary liquid, $\rho_0$ is density of the auxiliary liquid, and $\rho_L$ is air density ($0.0012 g/cm^3$).

Figure 7 shows the steps for density measurement by using METTLER TOLEDO balances device for solid porous.




(a) (b) (c) (d) (e)

Figure 7: Steps for density measurement by using balances device; a: Setup the setting in the device as solid porous in the method section, b: Put the sample on the pan, c: Soak the sample in oil and put it back on the pan, d: Put sample in basket, e: The balances give the density value.

## 3.4 Composites Fabrication

### 3.4.1 Rule of Mixture

The amount of reinforcements and the matrix were calculated based on the concept of rule of mixture. Equation 3 was used to determine the reinforcement and matrix weight needed for the composite fabrication process [19]. Table 5 shows the weight of reinforcement, epoxy and hardener needed to fabricate the polymer based composite.

$$\rho_c = \rho_f + \rho_m \text{...Equation 3}$$

Where: $\rho_c$ is the density of composite; $\rho_f$ is density of reinforcement; $\rho_m$ is density of matrix.

Table 5: Weight of reinforcement, epoxy and hardener needed for 5 wt.% of reinforcement composite.

| **(a) Material:** ***Coconut Short Fiber Composite (5 wt.%)*** | |
|---|---|
| Density of the coconut short fiber, $\rho_f$ ($g/cm^3$) | 0.444 |
| Density of the matrix, $\rho_m$ ($g/cm^3$) | 1.126 |
| Volume of composite, $V_c$ ($cm^3$) | 147.539 |
| Mass of coconut short fiber (g) | **11.582** |
| Mass of epoxy (g) | **137.530** |
| Mass of hardener (g) | **82.520** |

| **(b) Material:** ***Coconut Powder Composite (5 wt.%)*** | |
|---|---|
| Density of coconut powder, $\rho_f$ ($g/cm^3$) | 0.729 |
| Density of the matrix, $\rho_m$ ($g/cm^3$) | 1.126 |
| Volume of composite, $V_c$ ($cm^3$) | 147.539 |
| Mass of coconut powder (g) | **13.684** |
| Mass of epoxy (g) | **162.501** |
| Mass of hardener (g) | **97.500** |

The detail of calculation for the weight of reinforcement, epoxy and hardener needed to fabricate the polymer-based composite is shown in the Appendix I.

### 3.4.2 Preparation of Composites

Composites having same reinforcement weight of 5 wt.% were prepared by varying the shape and size of the reinforcement, which were in coconut short fiber and coconut powder. Firstly, a release agent or called as wax was used to clean and dry the mold before the epoxy can be laid up on the mold. The epoxy resin was then mixed uniformly with the hardener by using a special brush in the mixed container. Next, the fibers were spread evenly on the mold by using hand layup technique. Then, the mixture was poured carefully into the molds and flattened appropriately before being dried for 24 hours. After the composites were fully dried, they were separated off from the molds. Figure 8 shows the fabrication process for the bio-composite plate.

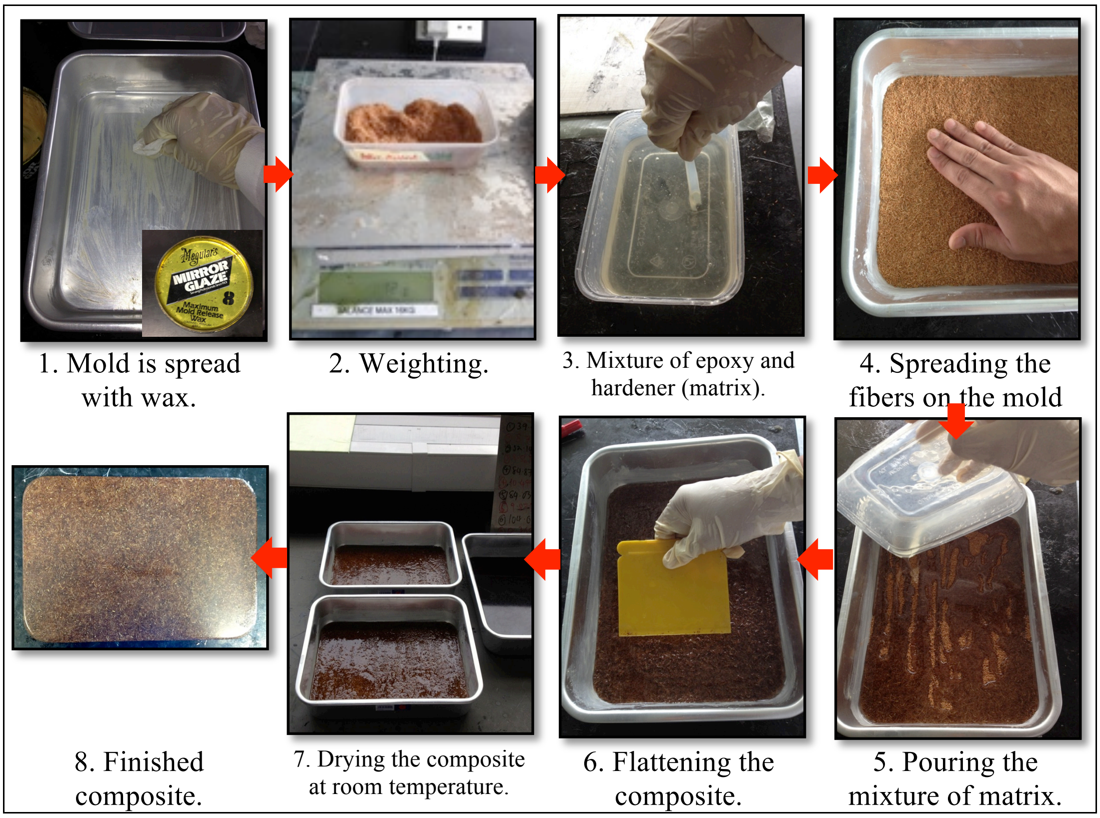



Figure 8: Fabrication process for coconut short fiber composite.

### 3.5 Mechanical Testing

The most common mechanical testing for determining the physical properties of materials such as strength, ductility, stiffness, elastic modulus and strain hardening are tensile test and flexural test.

The tensile test consist of applying a constant strain on the fibers and measure the load under the parameter condition set by the standard ASTM D3039 under the room temperature and humidity with Universal Testing Machine LLOYD [16]. The loading speed set was 2 mm/min. To tighten the gripper and prevent slipping from happening during the testing, a constant 5 N preload was applied for 5 second at the initial of the testing. Three specimens were prepared in the study for each shape of the reinforcement: short fibers and powder, in order to get more accurate results. Figure 9 shows the Universal Testing Machine LLOYD.

For flexural test, it was conducted under the parameter condition set by the standard ASTM D790 under the room temperature and humidity with Universal

Testing Machine LLOYD [21]. The software that integrated with this machine called NEXYGEN software. The specimen was placed onto two supports having a 40 mm span length between the supports. The crosshead speed was set to 10 mm/min. Three specimens were used for each shape of the reinforcement: short fibers and powder. Figure 10 shows flexural testing configuration setup.

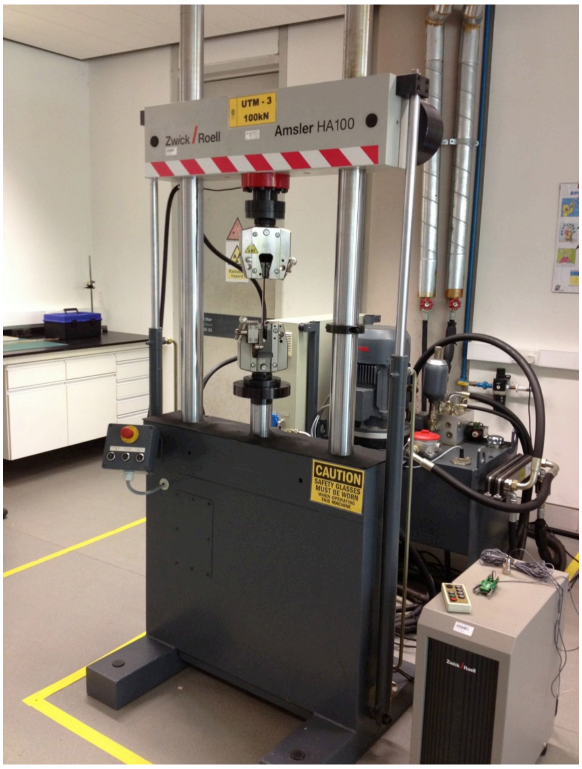
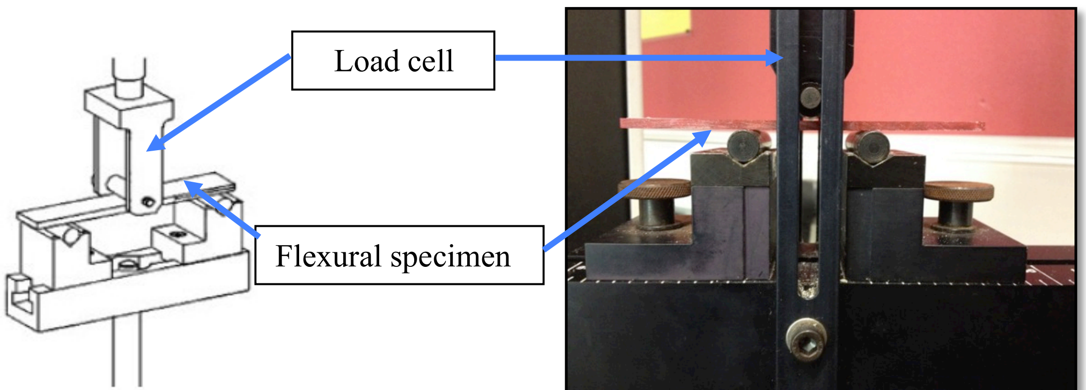



Figure 9: Universal Testing Machine LLOYD for tensile test.




(a) (b)

Figure 10: (a) Schematic showing loading scheme for flexural test; (b) Experimental setup for flexural test.

### 3.6 Microstructure Analysis

Optical Microscope observation was done to analyze the microstructure of the bio-composite. The machine used called Metallurgy Optical Microscope as shown in Figure 11. The magnification ranges utilized were 50x, 100x, 500x, and 1000x. Pictures were recorded and captured for each magnification ranges.

The fiber surface, matrix surface and interfacial between the fiber and matrix were three locations that were focused for the observation analysis.

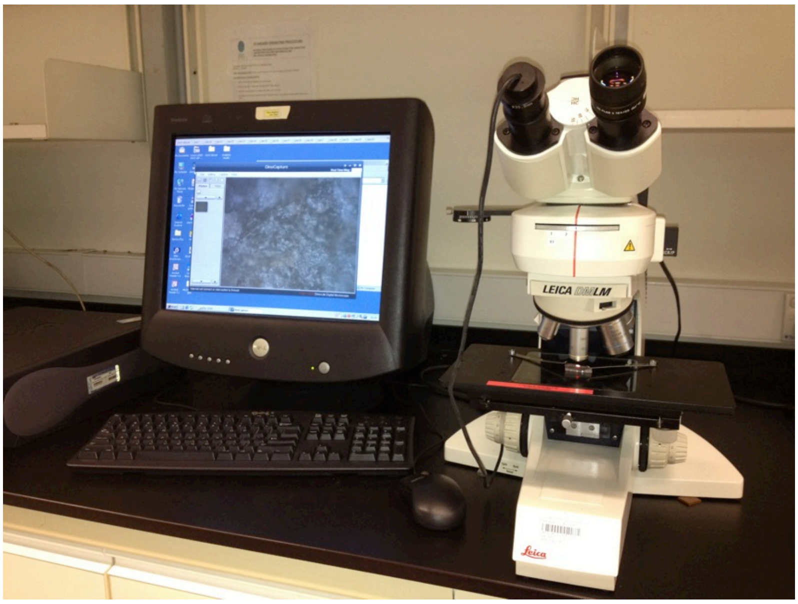


Figure 11: Metallurgy Optical Microscope machine for optical microscope analysis.

# CHAPTER 4
# RESULTS AND DISCUSSION

## 4.1 Fiber Preparation with Granulator

As received coconut fibers were grinded with the granulator Low Speed Granulator SG 16-21 machine. The entangled fibers were successfully been shortened into averagely even length as shown in the Figure 12.

Figure 12: As-received coconut fiber (left), granulator machine, (center) and coconut fibers after grinded with granulator (right).

## 4.2 Sieve Analysis

Sieve analysis has been conducted to analyze and determine the diameter range of the fiber to be used in the production of composite sample. After grinded process, even though the fiber length were mostly even, but there were some contaminants in the fibers such as small leaves, as well as there were obvious variations in the diameter of the fiber. Therefore, this sieve analysis has been done to filter out the contaminants. Result of the sieve analysis is shown in Table 6 and Figure 13.

The ranges of the apertures used for this analysis were from the biggest size of 2.000mm to the smallest 0.063mm (2.000mm, 1.180mm, 0.600mm, 0.425mm, 0.212mm, 0.150mm, and 0.063mm). The result in Table 6 shows that there were some weight losses for the coconut fiber weight after the sieve process has been done. The reason of weight loss was during the transferring process, of which to transfer the coconut fiber from the tray to the weight scale after the sieve process.

Table 6: Weight and percentage of fiber of different diameter range.

| Sieve size (mm) | Mass of fiber retained (g) | Percentage of each sieve (%) | Cumulative percent retained (%) | Percentage Finer (%) |
|---|---|---|---|---|
| 2.000 | 5.110 | 5.168 | 5.168 | 94.832 |
| 1.180 | 13.980 | 14.140 | 19.308 | 80.692 |
| 0.600 | 26.650 | 26.955 | 46.263 | 53.737 |
| 0.425 | 7.890 | 7.980 | 54.243 | 45.757 |
| 0.300 | 11.620 | 11.753 | 65.996 | 34.004 |
| 0.212 | 9.660 | 9.770 | 75.766 | 24.234 |
| 0.150 | 8.370 | 8.466 | 84.232 | 15.768 |
| 0.063 | 10.170 | 10.286 | 94.518 | 5.482 |
| Pan | 5.420 | 5.482 | 100.000 | |
| Total | 98.870 | 100.000 | | |

Total weight of the coconut fiber before sieve: 100.61g

Total weight of the coconut fiber after sieved: 98.87g

% Different of weight: 1.729%

Table 6 shows the weight of the fiber of different diameter range. The log graph as shown in Figure 13 has being plotted from the data in the Table 6. From the log graph, it can be observed that the stiffest curve is between 0.212mm to 1.18mm, which means more proportion amount of the fibers has the diameter within that range. In addition, the contaminants such as small leaves and larger diameter of fibers were trapped in the aperture size of 2.000mm and 1.180mm.

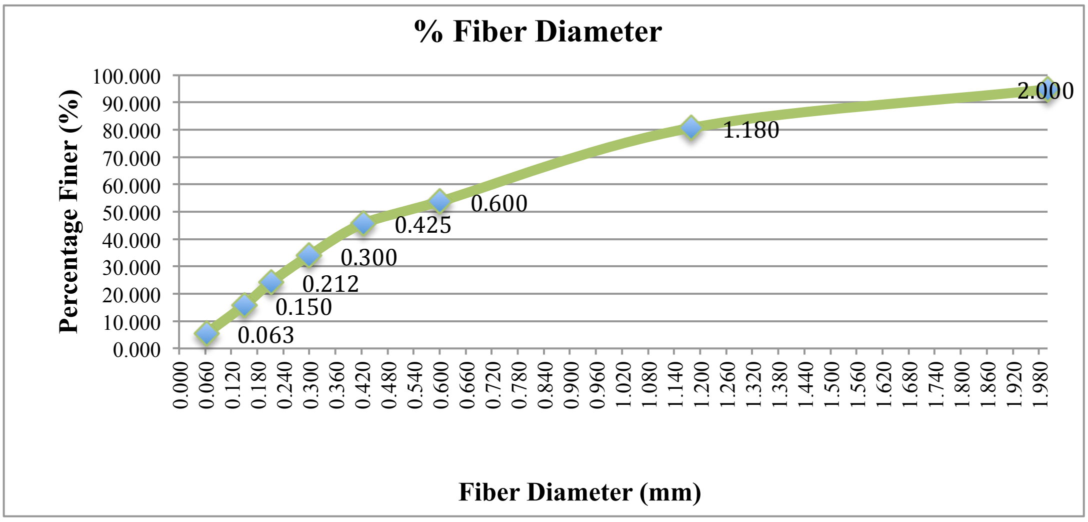



Figure 13: Fiber diameter distribution chart.

As conclusion, it was decided that fibers with the diameter range of within 0.212mm to 0.600mm were utilized for the fabrication of short fiber composite. Meanwhile, the coconut fibers with the size of 0.063mm and below were utilized for the fabrication of the coconut powder composite.

## 4.3 Density Measurement

Table 7 shows the result of density measurement for reinforcement. Referring to the Table 7, density value for coconut short fiber at pressure 600 kg/mm$^2$ was not taken into account for further calculation due to inconsistency of the result. It might due to some errors during conducting the experiment such as the specimen was not compacted enough and the sample was soaked too long in the oil. So, density value of coconut short fiber at pressure 500 kg/mm$^2$ and 700 kg/mm$^2$ were used to calculate the standard deviation and average. However for coconut powder, all density values were used, as the results were consistent. Density value for coconut short fiber and coconut powder from the Table 7 is plotted in the Figure 14.

Table 7: Density values for coconut short fiber and coconut powder.

| **Material: Coconut Short Fibers** | | | |
|---|---|---|---|
| Pressure (kg/mm$^2$) | Diameter (mm) | Thickness (mm) | Density (g/cm$^3$) |
| 500 | 22.36 | 4.59 | 0.39669 |
| 600 | 22.42 | 4.56 | 0.19853 |
| 700 | 22.40 | 4.49 | 0.49214 |
| **Material: Coconut Powder** | | | |
| Pressure (kg/mm$^2$) | Diameter (mm) | Thickness (mm) | Density (g/cm$^3$) |
| 500 | 22.50 | 3.24 | 0.75147 |
| 600 | 22.38 | 2.97 | 0.72532 |
| 700 | 22.43 | 3.10 | 0.70921 |

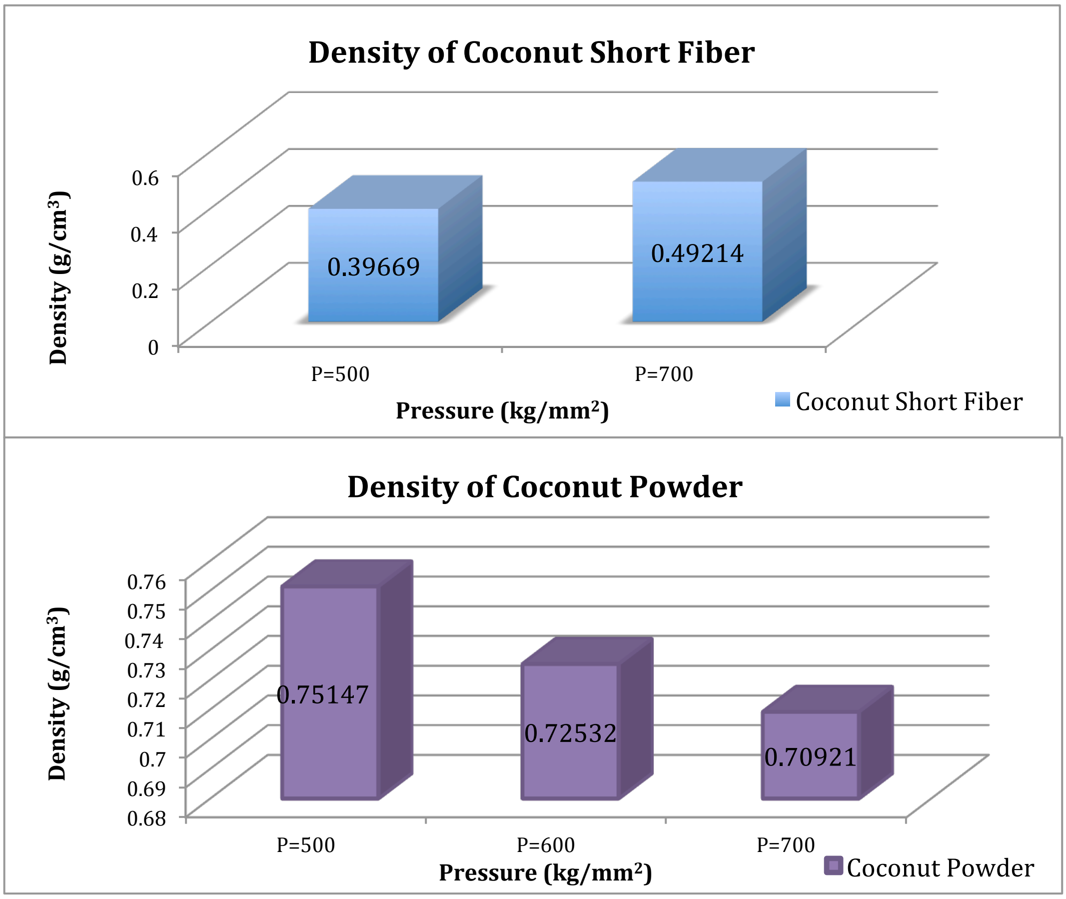



Figure 14: Density value for Coconut Short Fiber and Coconut Powder.

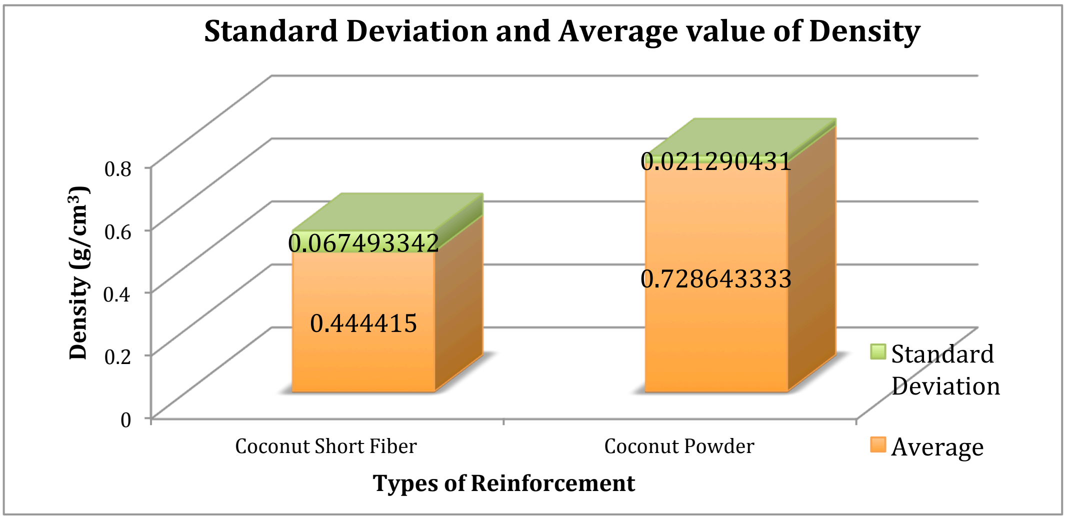



Figure 15: Standard deviation and average value of density for each reinforcement types.

Based on the Figure 15, the standard deviation gave a small value for coconut short fiber and coconut powder, which were only 6.75% and 2.12% respectively. Therefore, it means all density data from each pressure were closed to the average value. As conclusion, the density value for coconut short fiber and coconut powder was determined by applying the concept of Archimedes' Principle. Density of coconut short fiber was 0.444g/cm$^3$ and density of coconut powder was 0.729g/cm$^3$. These two values were used to determine the amount of reinforcement needed to fabricate the composite plate.

### 4.4 Tensile Test

Figure 16 and Figure 17 shows the Stress-Stroke curve for coconut powder epoxy composite, coconut short fibers epoxy composite, and 100 wt.% epoxy sample respectively, after the tensile test conducted. Then Figure 19, 20 and 21 shows the fracture mechanism of all the specimens. All the data obtained from this test is shown in the Table 8.

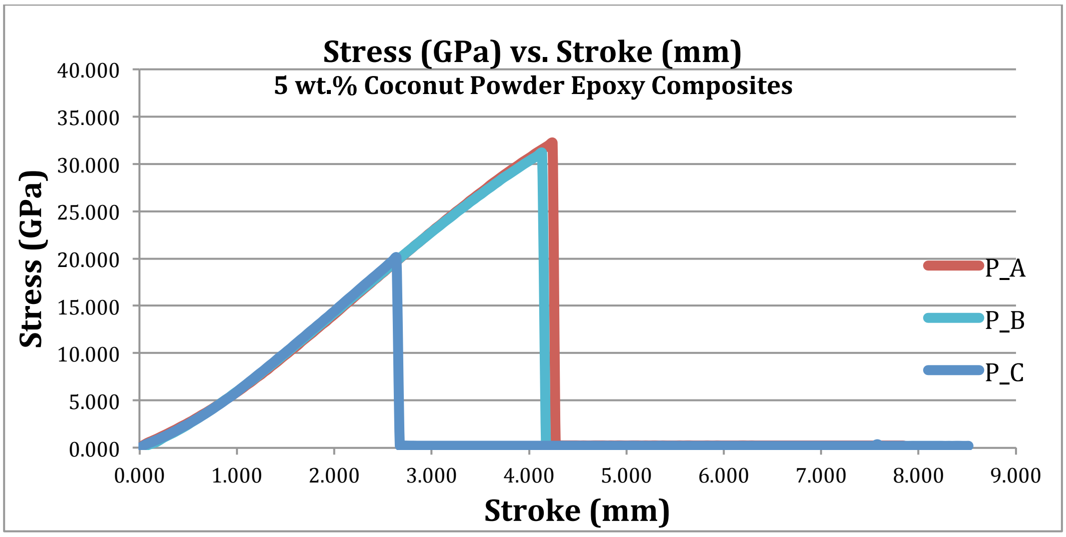



Figure 16: Stress-Stroke curve for 5 wt.% Coconut Powder Epoxy Composites.

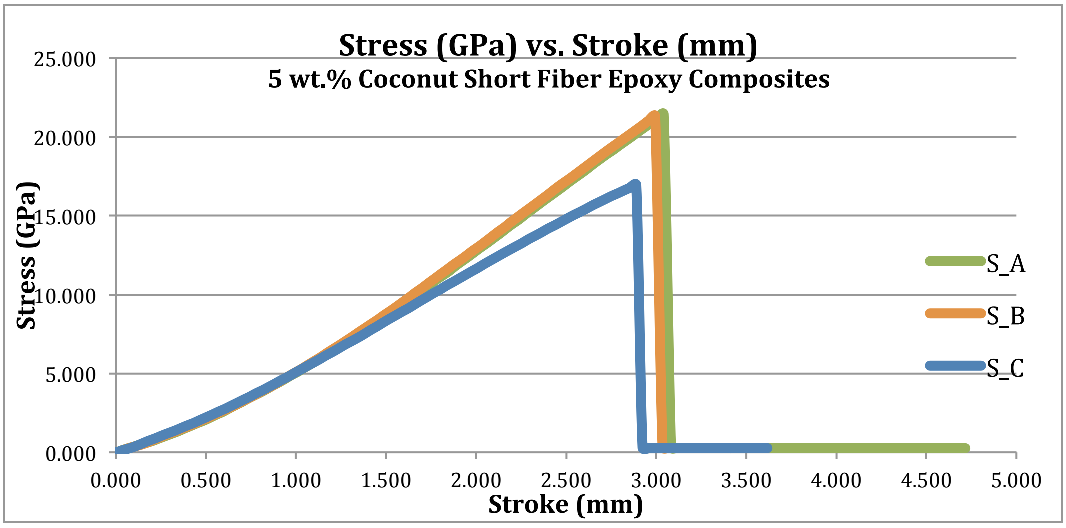



Figure 17: Stress-Stroke curve for 5 wt.% Coconut Short Fibers Epoxy Composites.

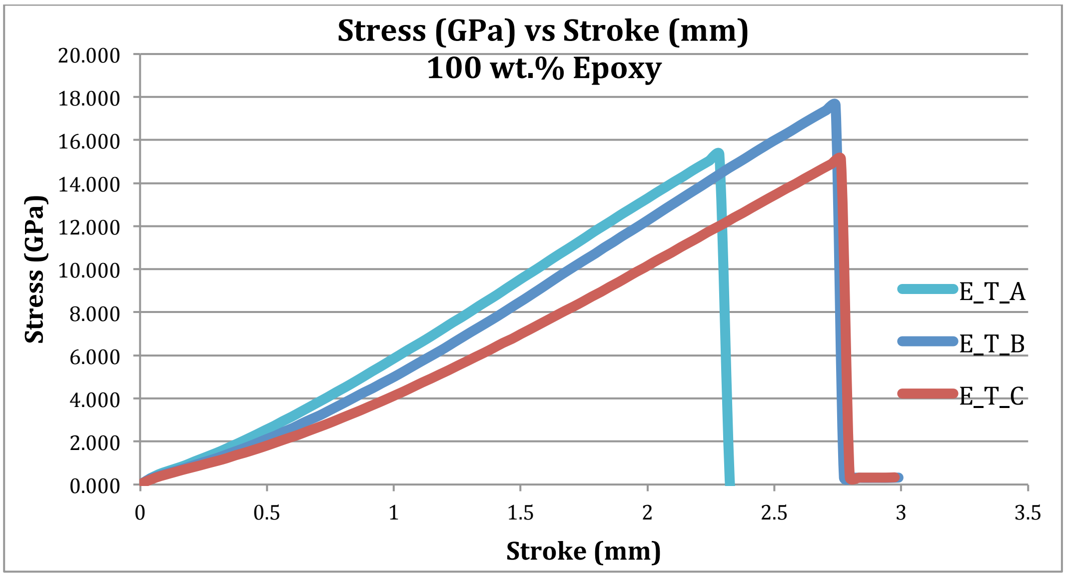



Figure 18: Stress-Stroke curve for 100 wt.% Epoxy.

Table 8: Result of Tensile Tests.

| Composites | Average & Standard Deviation | | | | | |
|---|---|---|---|---|---|---|
| | Peak Load (kN) | | Tensile Strength (GPa) | | Young's Modulus (GPa) | |
| 5 wt.% coconut powder epoxy | 3.80 | +0.158<br>-0.158 | 31.67 | +0.53<br>-0.53 | 2.42 | +0.29<br>-0.19 |
| 5 wt.% coconut short fiber epoxy | 2.36 | +0.007<br>-0.007 | 21.37 | +0.061<br>-0.061 | 2.14 | +0.28<br>-0.14 |
| 100 wt.% epoxy | 1.28 | +0.089<br>-0.089 | 16.48 | +1.145<br>-1.145 | 1.53 | +0.25<br>-0.13 |

Based on the Table 8, for coconut powder epoxy composite, the average value for tensile strength is 31.67 GPa and coefficient of variation (COV) is 1.67%. The average value for Young's modulus for this composite is 2.42 GPa and its COV is 8.02%. Meanwhile, for the coconut short fiber epoxy composite, the average value for tensile strength is 21.37 GPa and COV is 0.28%. The average value for Young's modulus for this composite is 2.14 GPa and its COV is 6.67%.

For 100 wt.% epoxy sample, the average value for tensile strength is 16.48 GPa and coefficient of variation (COV) is 6.95%. The average value for Young's modulus for this composite is 1.53 GPa and its COV is 1.54%. Therefore, the testing method used for this flexural test is reliable due to the percentage of COV is small and close to the average value.

Three samples have been used for the tensile test for each type of reinforcement. Referring to the Figure 16 and Figure 17, for 5 wt.% coconut powder epoxy composites sample and 5 wt.% coconut short fiber epoxy composites sample; it was noticed that the fracture point for the curve of sample P_C and S_C is lower compared with others. The reason is for both samples, the fracture occurred at the grip as shown in Figure 19 and Figure 20. Sample P_A, P_B, S_A, S_B, they fractured laterally within the gage length, not at the grip.

For 100 wt.% epoxy sample, it was noticed that for the curve of sample E_T_A, the fracture point is lower compared with sample E_T_B and E_T_C, as referring to the Figure 18. However, result obtained from the sample E_T_B and E_T_C were not to be considered for further calculation as the fractured occurred at the grip. Sample E_T_A fractured laterally within the gage length as shown in the Figure 21.

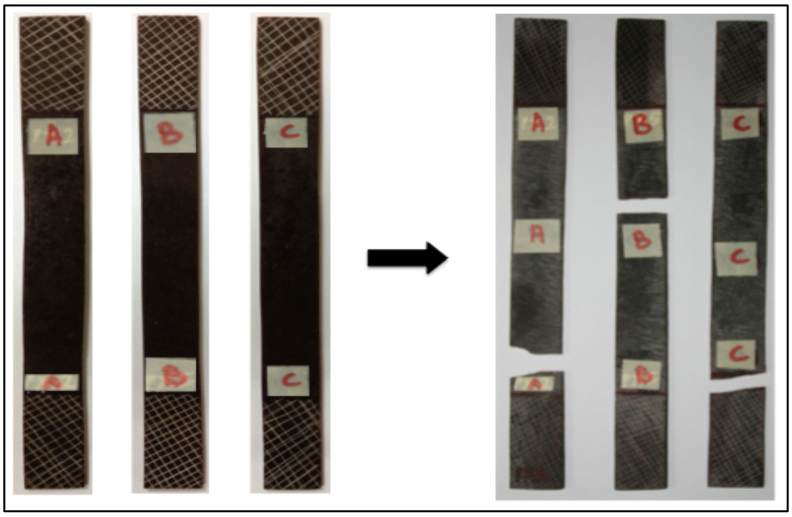



Figure 19: Composites sample of 5 wt.% coconut powder epoxy after testing.

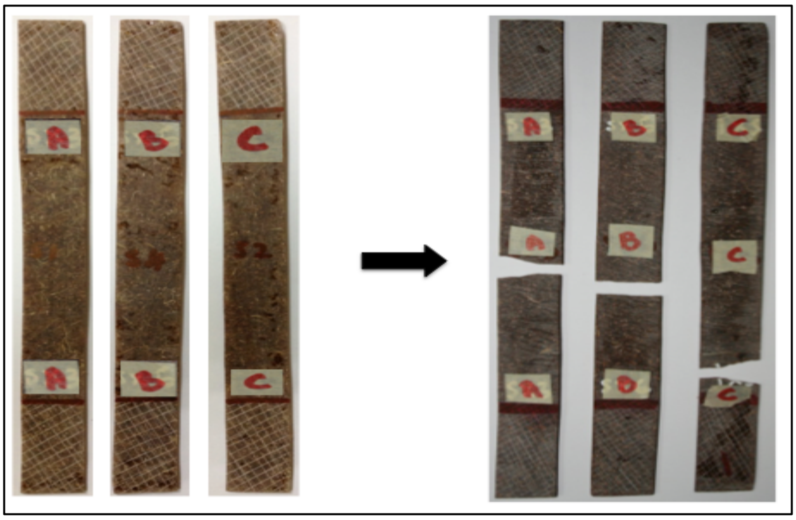


Figure 20: Composites sample of 5 wt.% coconut short fiber epoxy after testing.

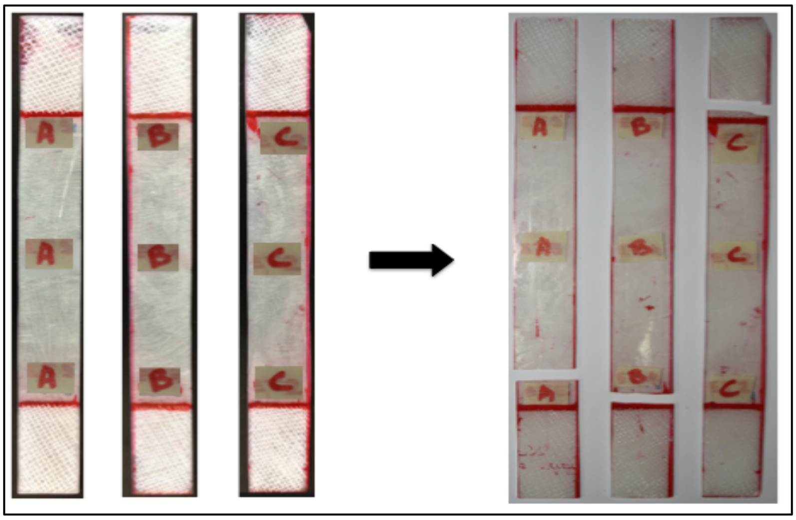


Figure 21: Composites sample of 100 wt.% epoxy after testing.

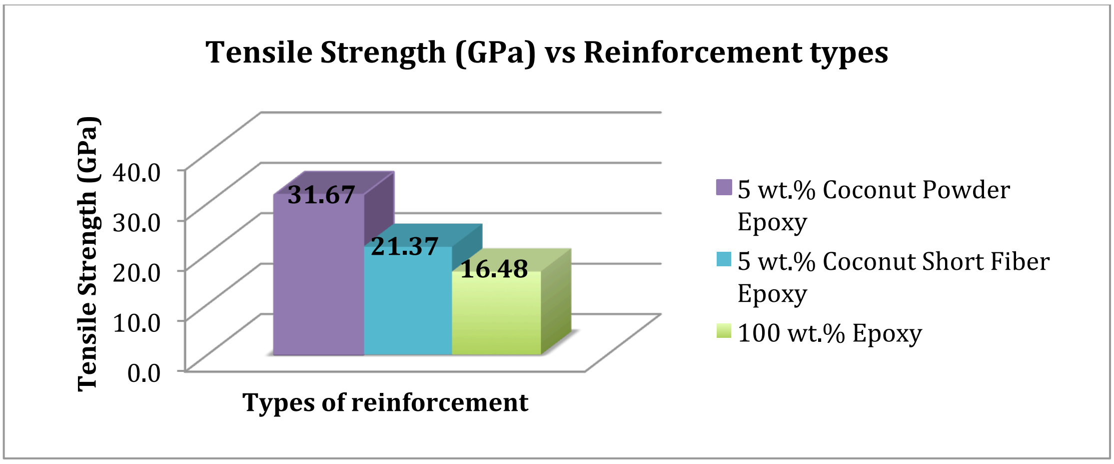



Figure 22: Column chart of Tensile Strength vs. Types of reinforcement.

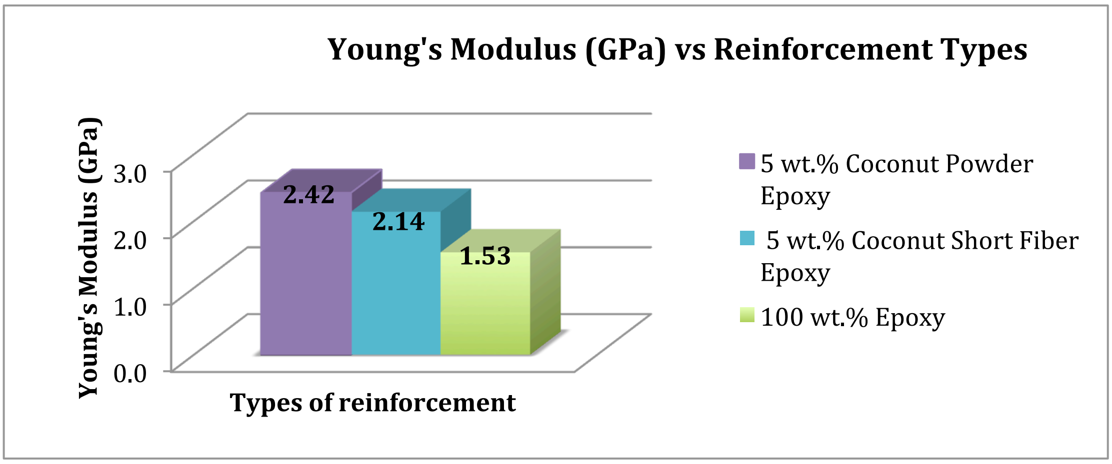



Figure 23: Column chart of Young's Modulus vs. Types of reinforcement.

Figure 22 and Figure 23 shows value of tensile strength and Young's Modulus in column chart. In this experiment, the chopped fiber distribution in epoxy is random, so the fiber could not hold the load when matrix was transferred. Doan et al. [22] stated that fiber length plays an important role in the mechanical performance of fiber-reinforced composites. On the factor that contributing to the lower experimental value is might due to the fiber was not perfectly aligned and the presence of voids in the composites. Based on the study that has been done by Baiardo et al., the mechanical properties of short fiber reinforced composites are expected to depend on (i) the intrinsic properties of matric and fiber, (ii) aspect ratio, content, length contribution and orientation of the fiber in the composite, and (iii) fiber-matrix adhesion that is responsible for the efficiency of load transfer in the composite [23].

5 wt.% coconut powder reinforcement epoxy composites show a higher value for both tensile strength and Young's Modulus compared with 5 wt.% coconut short fiber epoxy composites due to the better surface area of filler in the matrix as will affect the stability of the filler to support stresses transferred from the polymer matrix.

## 4.5 Flexural Test

Figure 24 shows the Bending Load-Deflection curve for all the specimens. The maximum load at fracture can be obtained from this test for each types of reinforcement. Flexural strength can be calculated by using the Equation 1 and also by the software that has been programed while performing the testing gave flexural modulus values. Next, average value and standard deviation for maximum load, flexural strength and flexural modulus were calculated. All the data were recorded in Table 9.

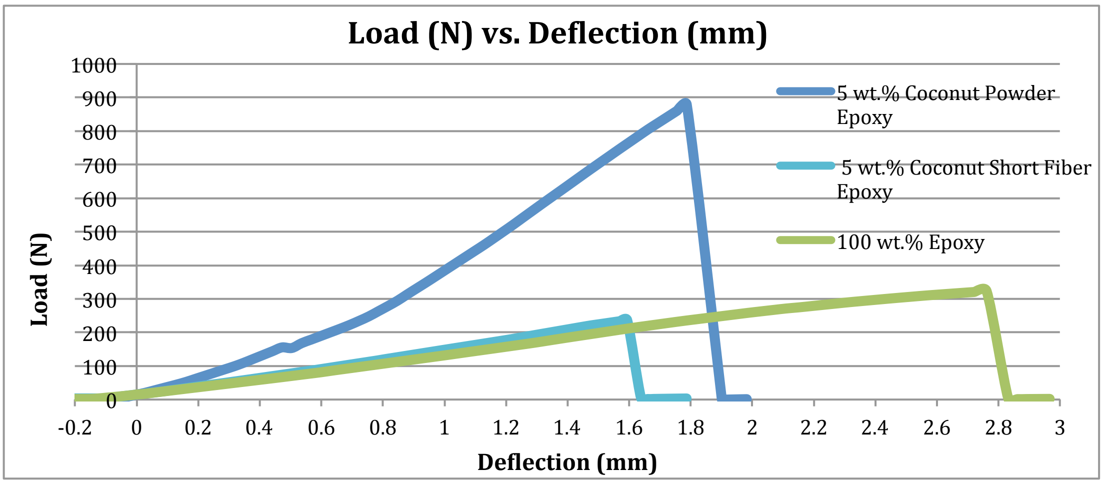



Figure 24: Graph of Bending Load (N) vs. Deflection (mm) for 5 wt.% coconut powder composites, 5 wt.% coconut short fibers composites, and 100 wt.% epoxy sample.

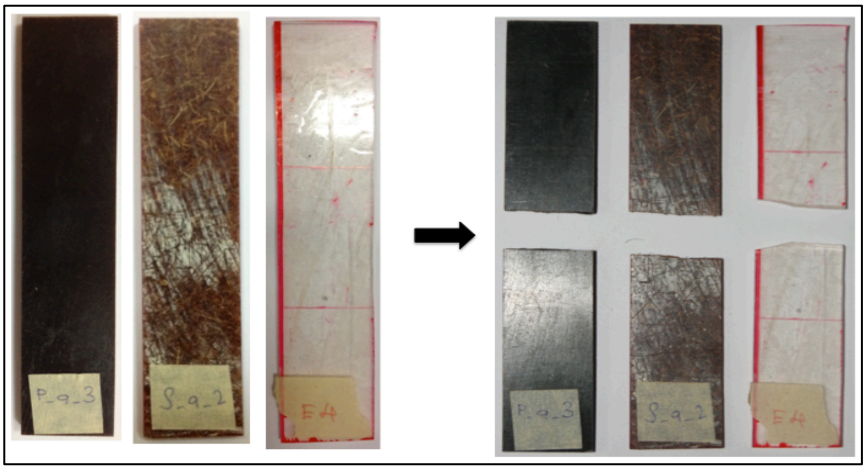


Figure 25: Composites sample of all specimens after the flexural test.

Table 9: Result of Flexural tests.

| Composites | Average & Standard Deviation | | | | | |
|---|---|---|---|---|---|---|
| | Maximum Load (N) | | Flexural Strength (MPa) | | Flexural Modulus (MPa) | |
| 5 wt.% coconut powder epoxy | 869.34 | +97.63<br>-152.19 | 68.23 | +6.55<br>-7.05 | 2518.85 | +283.34<br>-189.24 |
| 5 wt.% coconut short fiber epoxy | 224.85 | +13.64<br>-8.54 | 44.62 | +5.95<br>-4.93 | 2272.82 | +244.29<br>-124.96 |
| 100 wt.% epoxy | 324.96 | +23.02<br>-20.04 | 40.49 | +5.48<br>-4.95 | 1688.28 | +218.75<br>-148.27 |

Then, the average value for flexural strength and flexural modulus values of each types of reinforcement were drawn as the column chart as shown in Figure 26 and Figure 27.

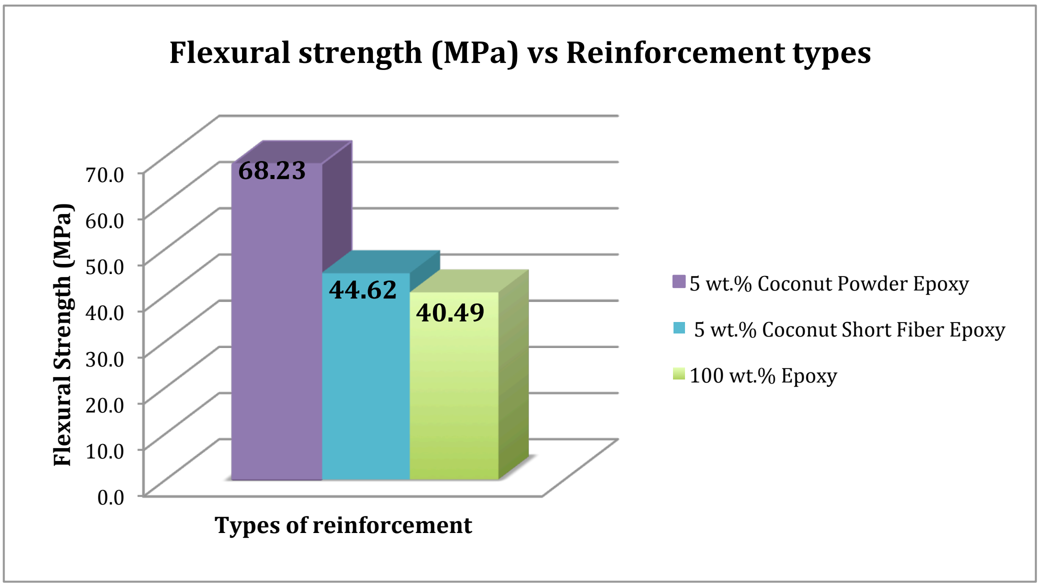



Figure 26: Column chart of Flexural Strength (MPa) vs. Types of reinforcement.

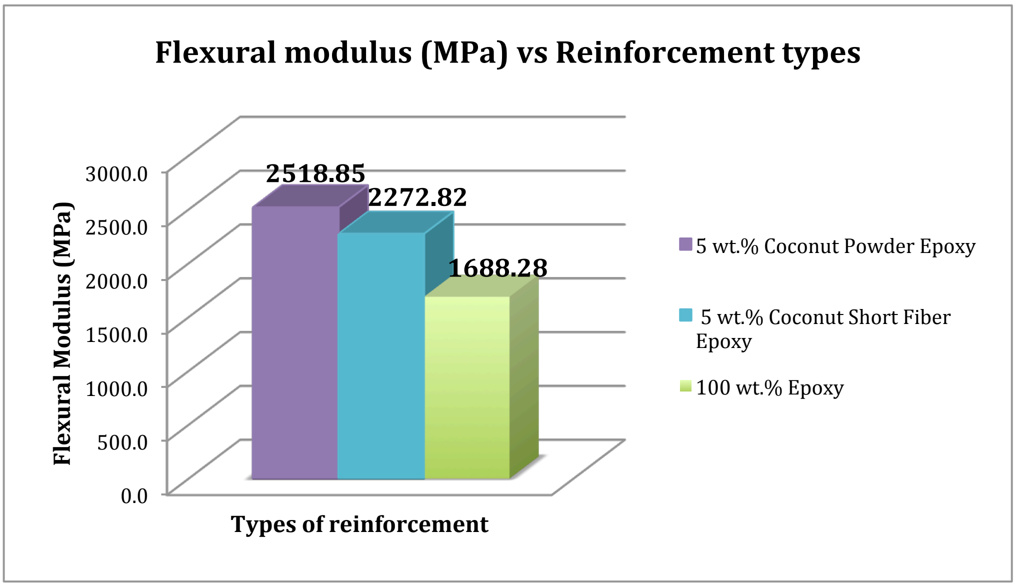



Figure 27: Column chart of Flexural Modulus (MPa) vs. Types of reinforcement.

From Figure 26 and Figure 27, the coconut powder is stiffer compared to the coconut short fiber for 5wt % of reinforcement. Referring to Table 9, for coconut powder epoxy composite, the average value for flexural strength is 68.23MPa and coefficient of variation COV) is 10.33%. The average value for flexural modulus for this composite is 2518.85MPa and its COV is 7.51%. Meanwhile, for the coconut short fiber epoxy composite, the average value for flexural strength is 39.64.23MPa and COV is 5.89%. The average value for flexural modulus for this composite is 2132.52MPa and its COV is 2.83%. Therefore, the testing method used for this flexural test is reliable due to the percentage of COV is small and close to the average value.

Based on the Table 9, 5 wt.% coconut powder epoxy composites indicated a higher value for both flexural strength and flexural modulus compared with others. The efficiency of stress transferred between matrix and reinforcement is higher for 5 wt.% coconut powder epoxy composite compared with others due to the strong interfacial region and better surface area of filler in the matrix. Factors that determine the quality of interfacial bonding include the nature of the fiber and binder as well as their compositions, the fiber aspect ratio, the types of mixing procedures and processing conditions employed [18].

## 4.6 Optical Microscope

The fracture surfaces study of coconut powder epoxy composite and coconut short fiber epoxy composites after the mechanical testing has been shown in Figure 28-30. It is noticeable that the breakage mechanism is brittle for all the specimens for both tensile test and flexural test.

Referring to the Figure 28, the coconut powder was well mixed with the epoxy. This indicated that a reasonable uniform distribution of coconut filler in the epoxy matrix.

Figure 29 and Figure 30 shows the interface between coconut fiber and the matrix. Figure 29 shows a micrograph indicated that there were small voids between the fibers and the matrix, which means the wetting, is not sufficient in this composite and poor interfacial bonding. The reason is due to short duration of time for the matrix to penetrate the fiber during the matrix was pouring on the top of the coconut short fiber. In addition, referring to Figure 30, it clearly observed that the slipping of the coconut fiber from the epoxy indicating that the compatibility between fibers and epoxy is poor, which is probably the cause of the poor for both tensile and flexural properties for the coconut short fiber epoxy composites compared with coconut powder epoxy composites.

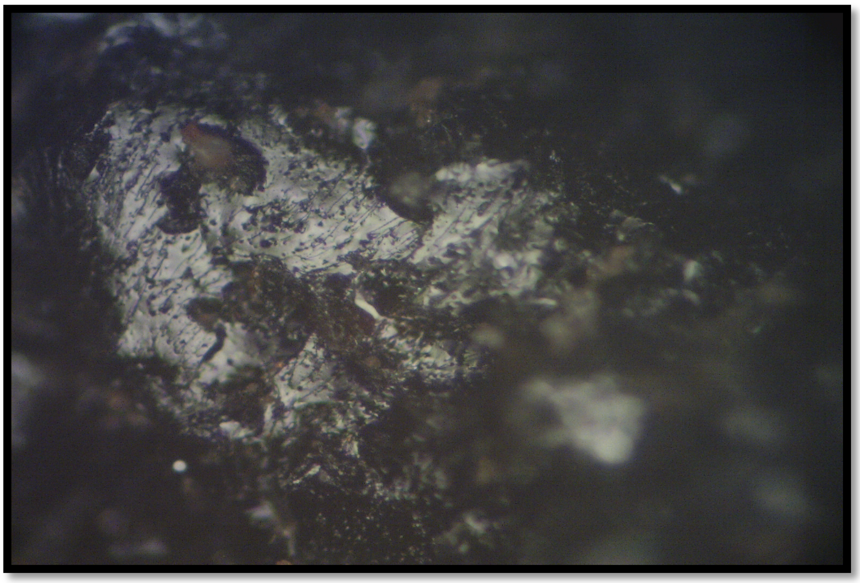


Figure 28: Optical micrograph for 5 wt.% coconut powder epoxy composite (magnification level-100x) after the tensile testing.

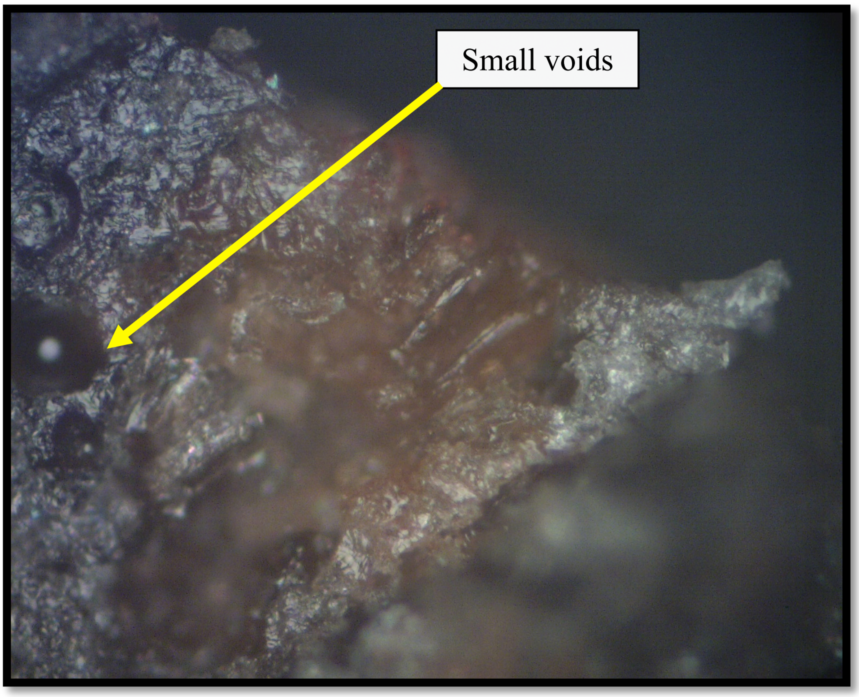



Figure 29: Optical micrograph for 5 wt.% coconut short fiber epoxy composite (magnification level-100x) after the tensile testing (present of small voids).

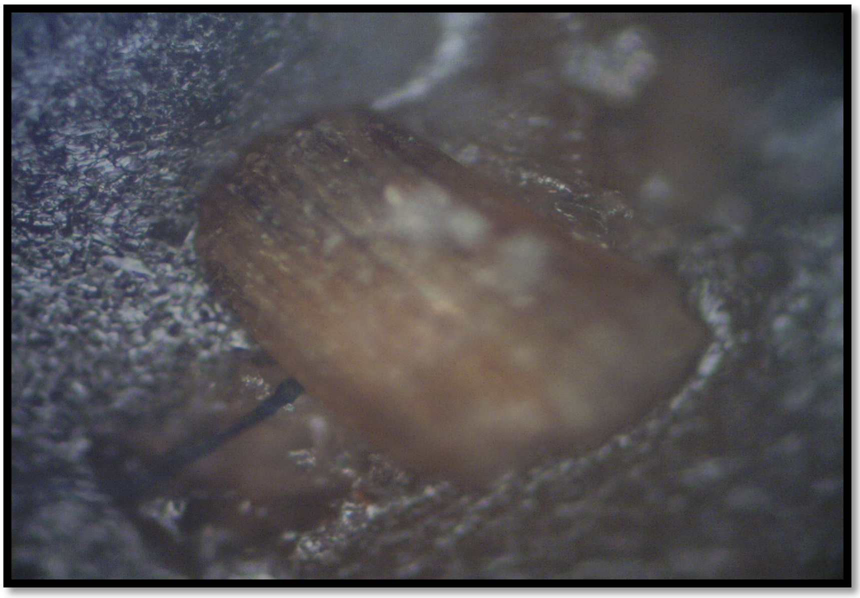


Figure 30: Optical micrograph for 5 wt.% coconut short fiber epoxy composite (magnification level-100x) after the tensile testing (splitting of fiber).

# CHAPTER 5
# CONCLUSION AND RECOMMENDATIONS

## 5.1 Conclusion

The objectives of the study have been achieved. It can be concluded that for 5wt. % of reinforcement, the coconut powder reinforced epoxy composites have better tensile strength (31.67 GPa) and Young's modulus (2.44 GPa) compared to the coconut short fiber reinforced epoxy composites with the percentage different of 32.53 % and 19.00 % respectively due to the better surface area of filler in the matrix. Under the flexural load, it was also can be concluded that the flexural properties of the coconut powder reinforced epoxy composites have better flexural strength (68.23 MPa) and flexural modulus (2518.85 MPa) compared to the coconut short fiber reinforced epoxy composites with the percentage different of 41.89 % and 15.34 % respectively.

## 5.2 Future Work Recommendations

For future research, it is recommended to do the water absorption analysis can be done on the bio-composites to prove the water resistance of the coconut fiber in the bio-composite. Besides, it is recommended by adding more variable value of the weight fraction of the reinforcement to improve of the result in future research.

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# APPENDICES

## Appendix I

Calculation for the weight of reinforcement, epoxy and hardener needed to fabricate the polymer-based composite.

(a) Coconut Short Fiber reinforced Epoxy Composite.

| Material: *Coconut Short Fiber Composite (5wt.%)* | |
|---|---|
| Density of the coconut short fiber, $\rho_f$ (g/cm$^3$) | 0.444 |
| Density of the matrix, $\rho_m$ (g/cm$^3$) | 1.126 |
| Volume of composite. $V_c$ (cm$^3$) | 147.539 |

Coconut Short Fiber: 5wt. %
Matrix: 95wt. %

$$\rho_c = \rho_f + \rho_m$$
$$\rho_c = 0.444\, g/cm^3 + 1.126\, g/cm^3$$

$$\frac{m_c}{V_c} = 1.57\, g/cm^3$$

$$m_c = 1.57\, g/cm^3 \times V_c = 1.57\, g/cm^3 \times 147.539cm^3 = 231.636\, g$$

$$\frac{m_f}{m_c} = 0.05$$

$$\therefore\ m_f = 0.05 \times 231.636g = \mathbf{11.582g}$$

$$\frac{m_m}{m_c} = 0.95$$

$$\therefore\ m_m = 0.95 \times 231.636g = 220.054g$$
Ratio of epoxy to the hardener for the matrix is 10:6.

$$\therefore\ m_{epoxy} = \frac{220.054g}{16} \times 10 = \mathbf{137.53g}$$

$$\therefore\ m_{hardener} = \frac{220.054g}{16} \times 6 = \mathbf{82.52g}$$

(b) Coconut Powder reinforced Epoxy Composite.

| Material: *Coconut Powder Composite (5wt.%)* | |
|---|---|
| Density of the coconut powder, $\rho_f$ (g/cm$^3$) | 0.729 |
| Density of the matrix, $\rho_m$ (g/cm$^3$) | 1.126 |
| Volume of composite. $V_c$ (cm$^3$) | 147.539 |

Coconut Powder: 5wt. %
Matrix: 95wt. %

$$\rho_c = \rho_f + \rho_m$$
$$\rho_c = 0.729\, g/cm^3 + 1.126\, g/cm^3$$

$$\frac{m_c}{V_c} = 1.855\, g/cm^3$$

$$m_c = 1.855\, g/cm^3 \times V_c = 1.855\, g/cm^3 \times 147.539 cm^3 = 273.685\, g$$

$$\frac{m_f}{m_c} = 0.05$$

$$\therefore\ m_f = 0.05 \times 273.685 g = \mathbf{13.684g}$$

$$\frac{m_m}{m_c} = 0.95$$

$$\therefore\ m_m = 0.95 \times 273.685 g = 260.001 g$$

Ratio of epoxy to the hardener for the matrix is 10:6.

$$\therefore\ m_{epoxy} = \frac{260.001g}{16} \times 10 = \mathbf{162.501g}$$

$$\therefore\ m_{hardener} = \frac{260.001g}{16} \times 6 = \mathbf{97.500g}$$

**Appendix II**

Final Year Project 1 Planning

| Details/Weeks | Jan | Feb | | | | March | | | | | | April | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
| Topic selection/confirmation | ❖ | ❖ | | | | | | Mid-Semester Break | | | | | | | |
| Preliminary Research Study coconut fiber/PE/natural fiber composite | | | | | | | | | | | | | | | |
| Submission of Extended Proposal Defense | | | | | | ❖ | | | | | | | | | |
| Laboratory equipment familiarization and experiments | | | | | | | | | | | | | | | |
| Fiber preparation: Fiber grinding and Sieve analysis | | | | | | | | | | | | | | | |
| Density Measurement of reinforcement | | | | | | | | | | | | | | | |
| Submission of Progress Report | | | | | | | | | ❖ | | | | | | |
| Proposal Defense | | | | | | | | | ❖ | ❖ | | | | | |
| Submission of Interim Draft Report | | | | | | | | | | | | | | ❖ | |
| Submission of Interim Report | | | | | | | | | | | | | | | ❖ |

❖ Key milestone

**Appendix III**

Final Year Project 2 Planning

| Details/Weeks | May | | June | | | | July | | | | | August | | | | Sept |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| Composite specimens fabrication | | | | | | | | Mid-Semester Break | | | | | | | | |
| Cut the composites into specimens | | | | | | | | | | | | | | | | |
| Tensile test | | | | | | | | | | | | | | | | |
| Flexural test | | | | | | | | | | | | | | | | |
| Observation (Optical Microscope) | | | | | | | | | | | | | | | | |
| Submission of Progress Report | | | | | | | | | | | ❖ | | | | | |
| Pre-EDX | | | | | | | | | | | | ❖ | | | | |
| Submission of Draft Report | | | | | | | | | | | | | ❖ | | | |
| Submission of Project Dissertation (Soft Bound) | | | | | | | | | | | | | | ❖ | | |
| Submission of Technical Paper | | | | | | | | | | | | | | ❖ | | |
| Oral Presentation | | | | | | | | | | | | | | | ❖ | |
| Submission of Project Dissertation (Hard Bound) | | | | | | | | | | | | | | | | ❖ |

❖ Key milestone